

Jacob smith report

by Jake Smith

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Data Capture & Evaluation

ACDA 6021

Jacob Smith

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Abstract

The intent of this report is to analyse a blast event to establish the nature of the device used. Various techniques were used to record the event from blast gauges, velocity foils and fragmentation capture medium. Using a list of possible devices and cross referencing it with the data captured at the trial along with open-source literature, a suggestion has been made as to what the most likely explosive device used in the event.

Introduction

A trial was conducted using an unknown munition in an explosives trial arena. The aim of this report is to use the data gathered as part of the trial to establish the most likely type of explosive device used in the trial. During the trial there were three main data capture devices used to record the event, Straw boards (captures fragmentation), velocity foils (used to determine fragmentation velocity) and blast gauges (used to record blast overpressure). Post the explosive event, there was two additional methods used to capture more data, the fragmentation was extracted from the strawboards and then swabbed. The swabs were then put through an FTIR machine to determine the explosives used within the device. The recovered fragmentation also had the parameters recorded (material type, number of fragments, total mass, average mass, average area of the frag and average thickness).

The explosive trial that took place was typical of what is called an explosives arena trial [1], these trials typically have the aim of capturing two key parameters of an explosion, Fragmentation and Blast pressure. From the methods used to capture these two parameters key performance metrics can be calculated. For example, using strawboards and velocity foils during an explosive trial, they can be used to calculate the fragmentation velocities and fragmentation patterns spread [2], aiding to evaluate a design or provide evidence to prove a theory (recreating a device used in a terror attack for example).

Method & Materials

As with any experiment there will be a selection of equipment and an associated method of deploying these equipment's. Below in table 1 it lists the key equipment used as part of this arena trial.

Equipment	Quantity used	Comments	Associated equipment
Blast gauges	3	Blast gauges were set up at 1.003m, 2.036m, and 3.016m away from the explosive device	• Stands • Cables to the recording equipment. • Protective casing for cables
Velocity foils	12	3 foils per strawboard stand. See Appendix A figure 14 for exact placement.	• Cables to recording equipment.
Strawboards	16	1.2m in height set up in an average of 1.57m away from the explosive device in a 113° arc. See	• Strawboard stands

		Appendix A figure 14 for exact details.	
Stand	1	Used to elevate the explosive device off the ground.	N/A
Firing box	1	Shrike Exploder unit	• Cable to explosive device initiator
Recording equipment	1	1x Computer 1x Oscilloscope	• No associated equipment all equipment is associated with other equipment (connection cables)

Table 1: Equipment list

For a typical arena trial there would also be several other additional equipment used during the explosion which haven't been used for this instance. The reason they haven't been used is due to the nature of the trial being a blind explosion. Blind in this instance means the device is not known and it is the purpose of this report to identify the most likely culprit using the equipment listed above and additional steps (swabbing and FTIR machine). This approach would be similar to the process undertaken by authorities (Police, EOD, DSTL etc) conducting a post blast analysis of an area that has experience an explosive event.

If this trial was to be conducted as a performance trial then there would be the inclusion of additional equipment such as High-Speed Video (HSV) and flash Xray imaging for example. Even if just one of these additional recording equipment's were included such as HSV, it would provide additional information in helping to determine the device.

As with any experiment there will be a planned-out method and approach to setting up and conducting this trial. These steps have been described below:

Pre trial- In the trial arena, the stands used for the strawboards were already in place and set up in a 113° arc at an average of 1.57m from the explosive site.

1. Determine the detonation site (this was pointed out by range staff).
2. Place strawboards on the stands, 4 packs per stand for a total of 16 packs.
3. Attach velocity foils to strawboards, 3 per stand for a total of 12 foils.
4. Measure and place the blast gauges stands at intervals from blast site for a total of 3 gauges, the distances were measured at 1.003m, 2.036m and 3.016m.
5. Attach blast gauges to the stands making sure they are in the correct orientation See Appendix A figure 13.
6. Run and attach cables to the blast gauges and the other end sent to the safe room housing the computer and oscilloscope.
7. Run and attach cables to the velocity foils and the other end sent to the safe room housing the computer and oscilloscope.

8. Connect all the cables to the appropriate recording equipment (computer and oscilloscope).
9. Turn on the recording equipment and load appropriate software for recording on the computer.

Figure 1 below shows the indicative set up of the explosive arena, Appendix A figure 16 shows the exact trial set up..

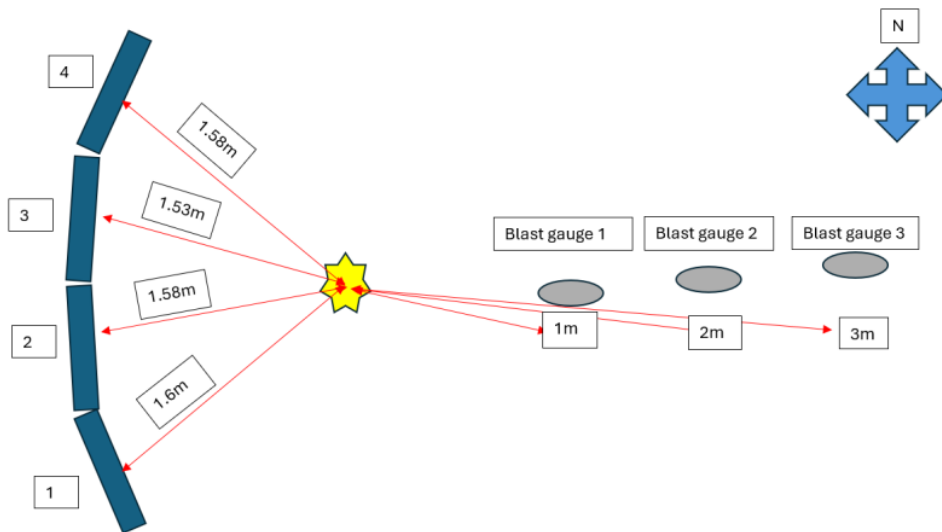


Figure 1: Graphic representation of the explosive arena.

At this stage all the explosive device, stand and firing box (plus associated firing line) were put into place out of site. This was done so the explosive device remained hidden from those intending to write this report. After this stage all personnel gathered within the safe room to initiate the device. After hearing the audible bang from the safe room, a member of Cotec¹ staff went to inspect the explosive area to confirm it was safe to re-enter the area.

Following all clear the following steps were undertaken on site and also back at the university's² OME lab.

1. Recorded data was saved on the recording devices.
2. Photos were taken of the strawboard.
3. Velocity foils were removed.
4. Fragmentation was removed from the strawboards and bagged.
5. In the OME lab the fragments were inspected, and parameters recorded.

¹ The range that was being used was owned and manned by Cotec, who are a subsidiary and commercial arm of Cranfield University.

² The university in question is the University of Wales Trinity Saint Davids who the author of this report is attending.

6. In the OME lab the fragments were submerged in a solvent to allow for the removed explosive residue to be tested on the FTIR machine.

Results

For ease of understanding the results will be broken down into four sections, Blast (pressure recorded by the blast gauges), Velocity (the speed at which the fragments impacted the velocity foils), Fragmentation (quantity, size, etc) and FTIR results.

Blast

The blast gauges recorded the following data transposed into a graph for better visualisation of the results.

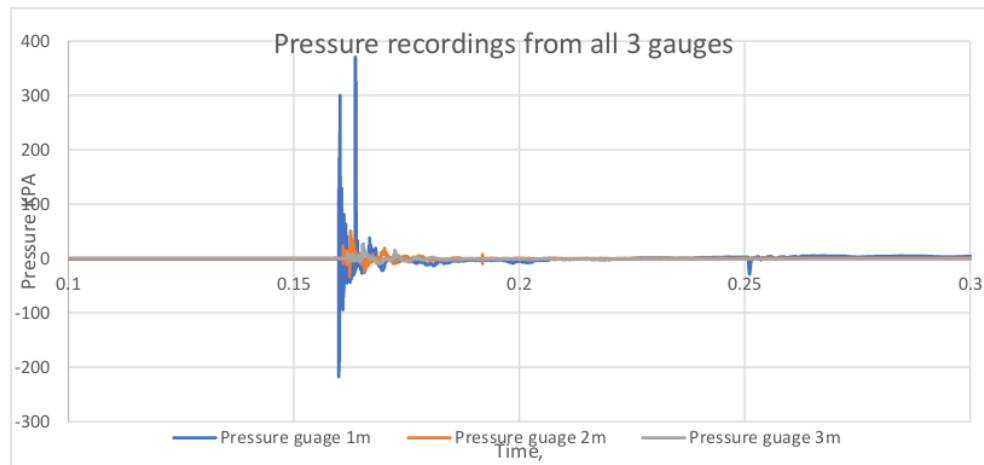


Figure 2: Blast gauges results for all 3 gauges time in Microseconds.

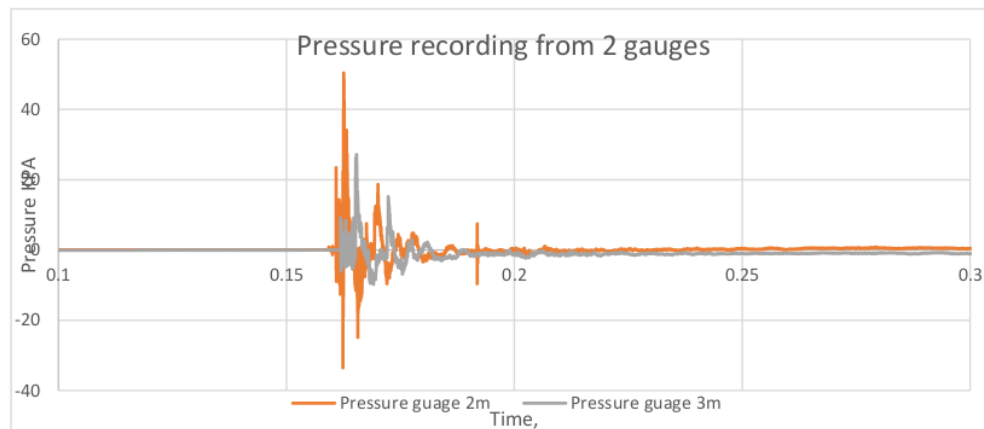


Figure 3: Blast results from 2m and 3m time in Microseconds.

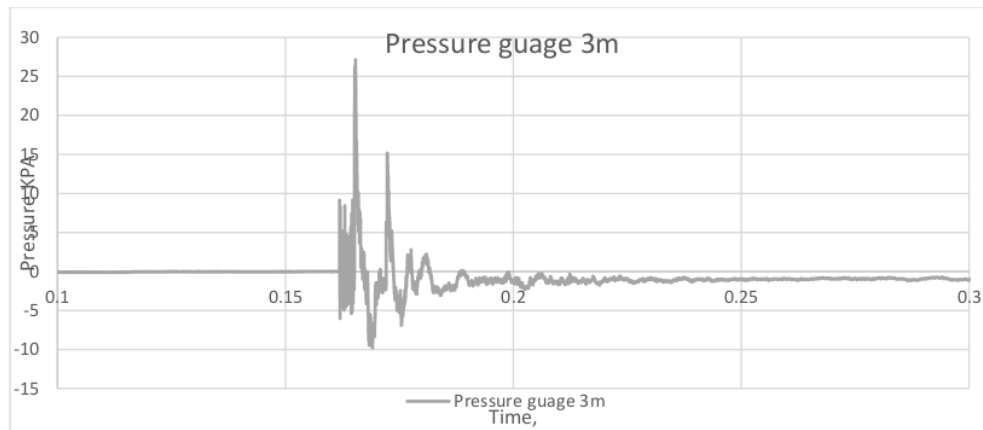


Figure 4: Pressure recorded at 3m time in Microseconds.

The pressure data these graphs show is summarised in the table below:

	Gauge at 1.003m	Gauge at 2.036m	Gauge at 3.016m
Pressure recorded	299 kPa	50 kPa	27 kPa

Table 2: Pressure data recorded.

In these graphs we can also see a second spike, most prominent in figure 2 towering above the initial blast pressure at 356 kPa. This can be attributed to the reflected blast pressure due to the explosive device being raised off the ground, reflected blast pressure waves are typically larger than the initial blast pressure [3]. The blast wave reached the first blast gauge in 0.16 Microseconds,

Velocity

Below in table 3 we can see the number of times and at what time after initiating the explosive device the fragments impacted the foils. It shows that some velocity foils such as foil 1 was impacted six times, foils 11 and 12 were only impacted once and foil 5 was not impacted at all according to the table but in fact it was impacted multiple times (see appendix A figure 20). The reason there are no recordings is due to the signal wire being severed from a fragment, this could also be the case as to why some foils have such low impacts but in the photos with Appendix A there shows multiple impacts. From this data the velocity of the fragments impacting the foils can be calculated with the simple formula of distance over time, which has been done below in table4.

Foil ID	Initial Strike Time from Trigger (ms)	Additional Strike Time from Trigger (ms)	Additional Strike Time from Trigger (ms)	Additional Strike Time from Trigger (ms)	Additional Strike Time from Trigger (ms)	Additional Strike Time from Trigger (ms)	Distance from charge to foil (ms)
1	1.14818	1.16342	1.20954	1.21438	1.22976	1.24564	1.635
2	1.15358	1.16518	1.41908	1.91314	2.04420		1.609
3	1.12476	1.14754	1.27588	1.29344	1.32382		1.570
4	1.14036	1.23266					1.531
5							1.605
6	2.19952	2.27682					1.606
7	1.08476	1.54112					1.554
8	1.13296	1.18522	1.18648				1.518
9	1.15976	1.2237	1.3647	1.41664			1.514
10	1.12384	1.26486	1.35510				1.529
11	3.46030						1.612
12	4.64982						1.587

Table 3: Velocity foil impact times.

	Impact velocity strike 1 M/S	Impact velocity strike 2 M/S	Impact velocity strike 3 M/S	Impact velocity strike 4 M/S	Impact velocity strike 5 M/S	Impact velocity strike 6 M/S
Foil 1	1423.99	1405.34	1351.75	1346.37	1329.53	1312.58
Foil 2	1394.79	1380.90	1133.83	841.03	787.10	
Foil 3	1395.85	1368.14	1230.52	1213.82	1185.96	
Foil 4	1342.56	1242.03				
Foil 5						
Foil 6	730.16	705.37				
Foil 7	1432.57	1008.36				
Foil 8	1339.85	1280.77	1279.41			
Foil 9	1305.44	1237.23	1109.40	1068.73		
Foil 10	1360.51	1208.83	1128.33			
Foil 11	465.86					
Foil 12	341.30					

Table 4: Foil impacts converted into velocities in Meters per second.

The velocities highlighted in yellow are significantly slower than the other impact velocities, this can be put down to possible ricochets off of the concrete floor in front of the strawboard/velocity foil stands. For a typical arena trial using these methods there would be a sandbag wall constructed approximately halfway between the explosive device and the strawboards and also approximately half the height the device was initiated at. This is done to ensure no ricochets are captured by the strawboard or velocity foils, due to the nature of this trial this was not done.

Fragmentation

As detailed above in the method undertaken on the day, the fragments were recovered from the strawboards, they were then analysing with all their parameters recorded. These parameters are listed below.

1. Material - steel, density 7860 kgm-3
2. Number of fragments - 138
3. Mass of all fragments - 154 g
4. Average mass of fragments - 1.116 g
5. Average fragment area - 28.05 mm²
6. Average fragment thickness - 1.24 mm

The fragmentation was then sorted and arranged as can be seen in figure 5 below. From this simple process we can determine that the fragmentation came from a naturally fragmenting casing. This is due to the random and non-uniform shapes created during the explosion [4].



Figure 5: Sorted and arranged recovered fragmentation.

Some of the fragments seen in figure 5 show what looks like copper stripes on their surface. Initially it was thought these could be due to the initiation device but was later found to be

the transfer of the copper wires contained within the velocity foils being transferred onto the fragmentation. This was proved when a fragment was matched to one of the holes in a velocity foil as shown below in figure 6.

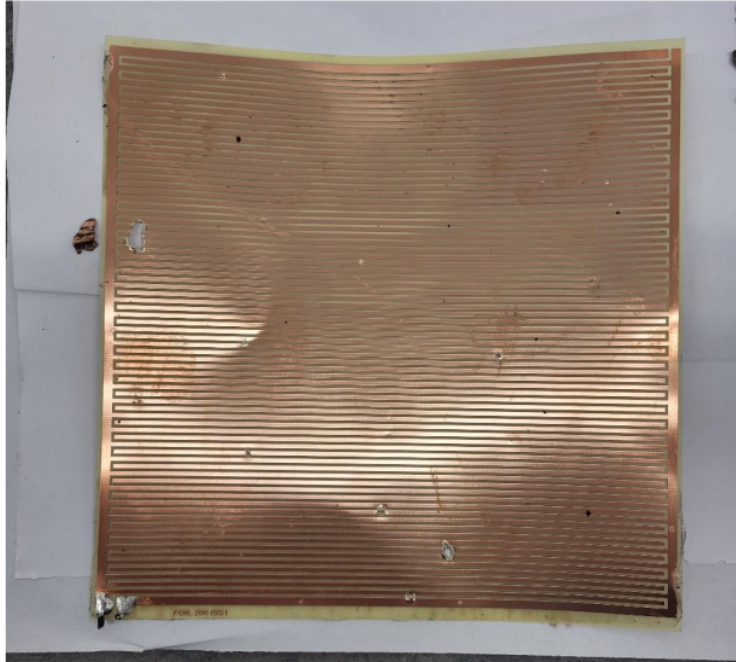


Figure 6: Velocity foil with copper coated fragment next to the hole it generated.

FTIR

The fragments were submerged in a solvent then samples tested by the FTIR machine to determine their composition. 50% of the fragments were submerged in Isopropyl alcohol and 50% in acetone, the isopropyl alcohol returned no significant results, but the acetone sample returned provided a reasonable result. This spectrum can be seen below in figure 7. With the knowledge that the explosive is soluble in acetone [5], [6] and combining that with the list of possible explosives contained within appendix B it can be assumed that the possible explosive composition is either RDX, TNT or even an RDX/TNT mix.

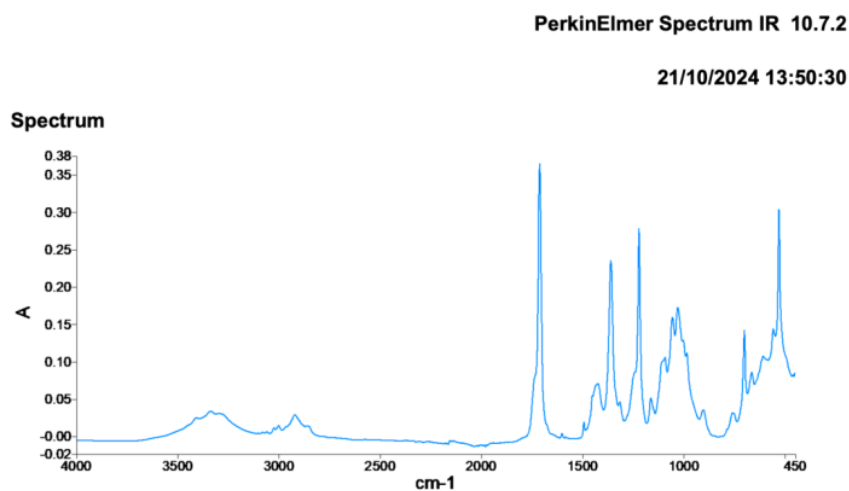


Figure 7: FTIR results from acetone solution.

Ideally the results from the FTIR machine would be automatically matched with those spectrums contained within the library the machine has access to. Unfortunately, in this instance this has not been done and also the peaks have not been labelled with the frequency numbers to assist with identifying the explosive. By comparing the peaks in figure 7 with those found in figure 8 it can be argued that the most appropriate answer to the explosive composition used within the explosive device is TNT. The 4 largest peaks in figure 7 match closely with those in the TNT graph (purple) of figure 8. Also combining this with the fact a benzene ring spectrum is present in figure 7 this further confirms the use of TNT as the main explosive fill for the device. A benzene ring is indicated by two sharp absorption peaks at approximately 1600 cm^{-1} and another one between $1500\text{--}1430\text{ cm}^{-1}$ [7]. A benzene ring is not present within RDX [8] therefore confirming the explosive composition used in this device was TNT.

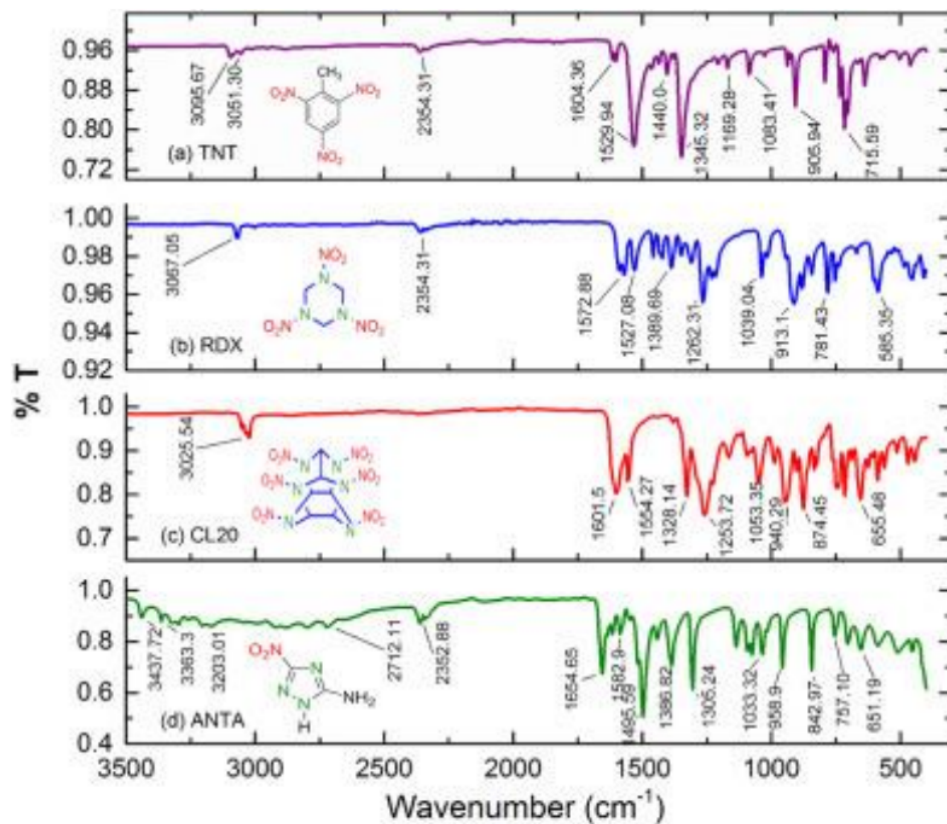


Figure 8: Comparison spectrum for 4 types of explosives [9]

Discussion

Using the data captured and discussed above and using the list of potential explosives devices in appendix B a process of elimination can be undertaken, the initial list contained the following devices:

- MK 83 Air Dropped munition.
- M-97 Grenade
- RGD-5 Grenade
- 81mm Mortar AR-M81
- RPG PG-7VL
- 155mm shell
- Pipe Bomb

Due to the arena having a small NEQ and the blast recordings being small in nature the larger munitions can be discounted. Any explosive device containing anything other than TNT can also be discounted along with anything containing preformed fragmentation. With

these considerations taken into account the remaining explosive article that could have been used in the event are either the RGD-5 grenade or the Pipe bomb.

The two remaining possibilities have the following parameters.

RGD-5 grenade

- Charge mass – 110 g
- Mass of case – 200 g
- AUW – 310 g
- Explosive – TNT
- Average frag area – 1.0 cm².
- Average frag mass – 0.12 - 0.46g
- Frag drag coefficient – 0.5
- Density of air – 1.29 kg m⁻³
- Frag Vi = 1567 ms⁻¹
- Number of fragments 350

Pipe Bomb

Charge mass – 200 g.
Mass of case – 200 g
AUW – 400 g
Explosive – TNT

Average frag mass – 0.23g
Frag drag coefficient – 0.5.
Density of air – 1.29 kg m⁻³
Frag Vi = 1990 ms⁻¹

Comparing these parameters to the results discussed above the most likely explosive device is the RGD-5 grenade. This is because although the results and parameters are very similar the fragment velocity is the closest matching parameter. It could also be argued that if some of the larger fragments collected could be disregarded and a closer average frag mass could be seen between what was collected and what the RGD-5 parameters have.

The reason for stating to disregard the larger fragments is due to the fact the device would have had to have been set off by an approved detonation method at the Cotec range. What this method is, is unknown but can be assumed due to the use of a shrike that it is a conventional detonator and not the devices own detonator. Due to this the grenade would not have had its typical “plug” in place on top resulting in an exposed area to vent off some of the detonation gasses, resulting in a loss of performance. With this loss of performance, it could be argued the larger fragments came from this area as they had less force imparted on them to shatter into smaller fragments. This gas venting could also be the reason for a slight less (100m/s) velocity recorded to that listed in the parameters.

Conclusion

Reviewing all the data captured in the results and cross referencing this with that of the provided list of devices it can be stated with confidence that the device at the explosive site was a Russian designed RGD-5 grenade.

There are several matching parameters that include the explosive composition, naturally fragmenting casing, fragmentation velocity, blast pressure and fragments recovered, with table 5 below showing the matches.

Parameter	RGD-5 grenade	Results captured	Comments
Explosive fill	TNT	TNT	Matching
Average Frag velocity	1567 m/s	1271 m/s	Close match. RGD-5 frag velocity is unknown at what range this is taken from but closest match to the remaining likely munitions
Average Frag type	Natural	Natural	Matching
Average Frag mass	0.12g to 0.46g	1.116g	As stated above, removing largest frags could even out the average mass making these parameters closer
Blast pressure	277 kPa*	299.8 kPa	Close matching results. *RGD-5 pressure was calculated using Kingery Graham calculation.

Table 5: Result comparison

Therefore, it can be stated with reasonable confidence the device used in this explosive event was the RGD-5 grenade. To be able to fully confirm if this was indeed an RGD-5 grenade then a repeat trial (ideally more than 1 trial) should be conducted with the results from that trial compared with the one discussed in this report.

References

- [1] T. W. A. W. T. e. a. Payne, "Large-scale explosive arena trials," *Explosive Engineering*, pp. 10-16, 2016.
- [2] P. Q. S. B. R. H. R. C. James Read, "Sustainable and economical alternatives to fragment capture materials in explosive and ballistic trials," *Forensic Science, Medicine and Pathology*, 2024.
- [3] D. Weggel, *Blast threats and blast loading*, Charlotte: Woodhead Publishing, 2010.
- [4] J. T. A. C. Berko Zecevic, "INFLUENCE OF WARHEAD CASE MATERIAL ON NATURAL FRAGMENTATION PERFORMANCES," in *15th International DAAAM Symposium*, Vienna, 2004.
- [5] T. Z. M. W. Fang Chen, "Spheroidal crystal morphology of RDX in mixed solvent systems predicted by molecular dynamics," *Physics and Chemistry of Solids*, vol. 136, no. 0022-3697, 2020.
- [6] D. K. Caflin, "SOLUBILITY REPORT OF 2,4,6-TRINITROTOLUENE (TNT)," Munitions Engineering and Technology Center, New Jersey, 2022.
- [7] X. Liu, *Organic Chemistry*, KPU, 2021.
- [8] J. Akhavan, *The Chemistry of Explosives*, Cambridge: The Royal Society of Chemistry , 2011.
- [9] D. G. F. Y. A. C. K.S. Rao, "A comparative study of thermal stability of TNT, RDX, CL20 and ANTA explosives using UV 266 nm-time resolved photoacoustic pyrolysis technique," *Molecular and Biomolecular Spectroscopy*, vol. 211, no. 1386-1425, pp. 212-2020, 2019.

Appendices

Appendix A: Photos from trial



Figure 9: Blast gauges used in the trial.



Figure 10: Strawboards being put in place.



Figure 11: Velocity foil cables.

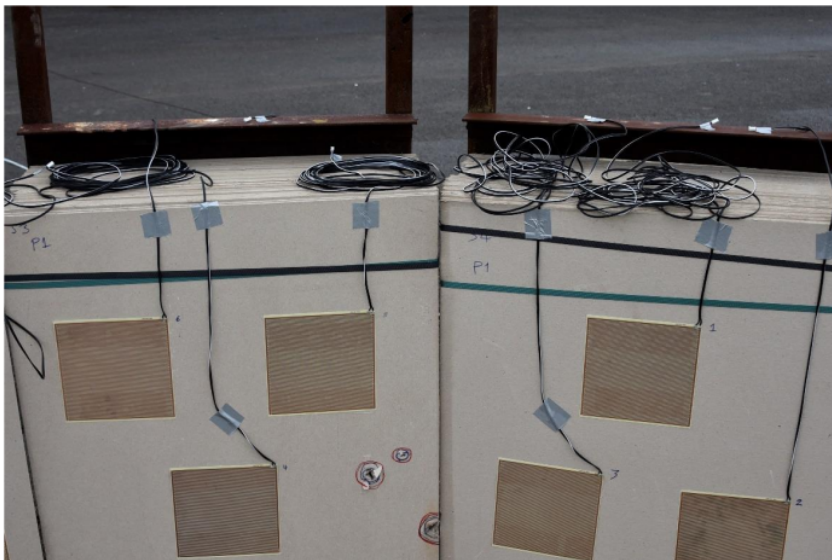


Figure 12: Velocity foils in place.



Figure 13: Blast gauges in place.



Figure 14: Velocity foils in place.



Figure 15: Velocity foil cables and waterproof box used to provide environmental protection to the cable connections.



Figure 16: Blast site before detonation.



Figure 17: Strawboard post explosion showing fragmentation pattern.



Figure 18: Strawboards used to place the explosive stand on, some fragmentations were extracted from this board.

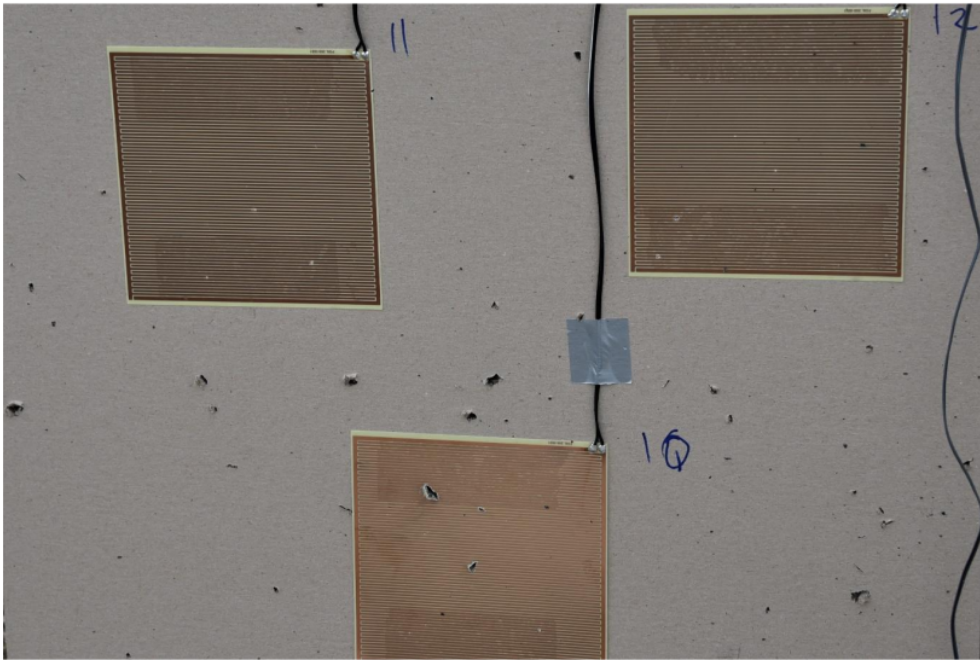


Figure 19: Close up of fragmentation pattern in strawboard.



Figure 20: Close up of fragmentation pattern in strawboard.

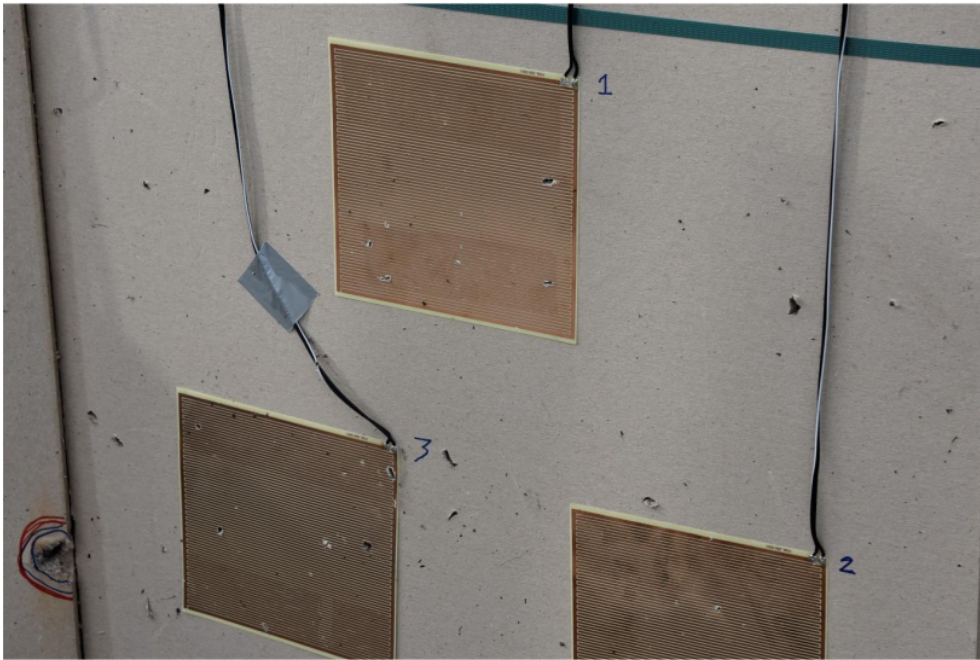


Figure 21: Close up of fragmentation pattern in strawboard.



Figure 22: Frag impact on blast gauge stands.



Figure 23: Frag impact on gauge stand.



Figure 24: Frag impact on blast gauge protection.

Appendix B: Types of Munitions of Potential Interest

Mk 83 air dropped munition.

- Charge Mass – 225 kg.
- Mass of case – 229 kg
- AUW – 454 kg
- Explosive – Comp B
- Average fragment area - 0.48 cm²
- Average fragment mass – 0.115 kg
- Frag drag coefficient – 0.82.
- Density of air 1.23 kg m⁻³
- Frag V_i = 1950 ms⁻¹
- Frag V_f = 1911 ms⁻¹ at 92 m

M-67 grenade

- Charge mass – 185 g.
- Mass of case – 213 g
- AUW – 398 g
- Explosive – Comp B
- Average frag area – 1.0 cm².

- Average frag mass – 2g.
- Frag drag coefficient – 0.5.
- Density of air – 1.29 kg m⁻³
- Frag V @ 5m -1674 ms⁻¹.
- Frag V @ 15m – 1424 ms⁻¹.
- Frag V @ 230 m – 44 ms⁻¹.

RGD-5 grenade

- Charge mass – 110 g.
- Mass of case – 200 g
- AUW – 310 g
- Explosive – TNT
- Average frag area – 1.0 cm².
- Average frag mass – 0.12 - 0.46g
- Frag drag coefficient – 0.5.
- Density of air – 1.29 kg m⁻³
- Frag Vi = 1567 ms⁻¹
- Number of fragments 350

81 mm Mortar AR-M81

- Charge Mass – 0.76 kg.
- Mass of case – 1.334 kg
- AUW – 4.15 kg
- Explosive – TNT
- Frag drag coefficient – 1.6.
- Density of air 1.23 kg m⁻³
- Frag Vi = 1734 ms⁻¹
- Frag V @ 1m – 1700 ms⁻¹.
- Frag V @ 4m – 1600 ms⁻¹.
- Frag V @ 20m – 1150 ms⁻¹.
- Frag V @ 32m – 900 ms⁻¹.
- Frag V @ 77m – 357 ms⁻¹.

RPG PG-7VL

- Charge mass – 730 g.
- Mass of case – 1600 g (including rocket motor)
- AUW – 1975 g
- Explosive – RDX/TNT - 95% HMX 5% wax
- Average frag mass – 0.1 g.
- Density of air – 1.29 kg m⁻³
- Frag Vi -1831.5 ms⁻¹.

155 mm

- Charge mass – 1150 g.
- Mass of case – 3105 g
- AUW – 4255 g
- Explosive – Comp B
- Average frag mass – 2.1g
- Density of air – 1.29 kg m⁻³
- Frag Vi -1551 ms⁻¹.

Pipe Bomb

- Charge mass – 200 g.
- Mass of case – 200 g
- AUW – 400 g
- Explosive – TNT
- Average frag mass – 0.23g
- Frag drag coefficient – 0.5.
- Density of air – 1.29 kg m⁻³
- Frag Vi = 1990 ms⁻¹

Jacob smith report

GRADEMARK REPORT

FINAL GRADE

68/100

GENERAL COMMENTS

Dear Jake,

Overall, this was a good assignment, scoring in the high 2:1 bracket. You clearly understand the concept of data capture and evaluation but there could have been a number of improvements in presentation. Please look at the constructive points offered below and take them forwards in your Major Project.

In detail:

The assignment was well laid out and easy to follow. It was quite a bit over on the word count but much of that was in the supporting detail.

Good use of tables, figures and imagery to describe the report and its findings. I particularly liked Table 1, which summarised the key equipments very well.

Good point on other systems such as HSV to further improve the capture and evaluation aspects of the trial.

Very clear description of method and materials, again with useful supporting imagery.

Clear breakdown of results into obvious sections, well done.

Try to quickly explain why the reflected overpressure is higher than the incident overpressure. I note you have used the correct reference, but perhaps Kinney & Graham would have been more precise.

A bit of a long and clumsy sentence under your velocity heading on page 8. Try and break it down into 2 sentences. Good spot though on cables being cut and other real-life 'stuff' that happens on trials, such as ricochet reducing velocity (and even fragment size). Again, clumsy last sentence in the velocity section - done is not a technical term, and id distracting used twice in one sentence.

No issues on fragmentation but it would have been useful for the trail team to have remembered which fragmentation came from which strawboard.

Again, I liked your description of the IR spectrum. You could have been so bold as to identify the chemical fingerprints on the spectrum itself; this would have made the reader's life slightly easier. But yes, clear indication of a benzene ring. Unequivocal match to TNT but watch the contamination from the acetone - this could sometimes mask other signatures.

In the discussion, you could have laboured slightly longer on discounting the munitions other than the RGD-5 and pipe bomb. What if your FTIR result had been contaminated, or the RDX obscured for example?

Again, a clumsy paragraph below your tabulation of ordnance properties on page 14. Try and get a peer review to confirm that all reads well before you submit.

Never put a table in a conclusion. This should be your unequivocal finding, which must be absent of superfluous supporting data. For example: This trial demonstrates that the fragmentation and blast parameters recorded on the trial indicate a small munition such as the RGD-5 or pipe bomb. FTIR analysis confirms the chemical composition as TNT, again suggesting both types of munition. However, fragmentation and blast overpressure findings suggest that the RGD-5 is the most likely candidate. Given that only one firing was conducted, this assessment

Referencing good and hugely informative Appendices.

Finally, a bit of confusion in parts over the use of was and were, which became slightly distracting during reading. At level 6 please work on this, particularly in the marks that will be awarded for the Major Project (75% of 40 credits).

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